

# Experimental and Numerical Characterization of Stress-Strain Fields on Sandwich Beams Subjected to 3PB and 4PB

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**Abstract** This work aims to evaluate and characterize the stress-strain fields in sandwich beams subjected to 3PB and 4PB. The correlation between the experimental and the finite element analysis are presented and allows to a better knowledge and understanding of the complex stress-strain fields in sandwich beams when subjected to bending loading. 3D finite element models were carried out using Siemens NX10 for assessing at three- and four-point-bending tests of sandwich beams with different conditions: two lengths of span (short- and long-beam); two core thicknesses (20 and 30 mm); and two different face materials (aluminum and basalt fiber reinforced polymer). The results obtained in the 3D finite element analyses were compared with the experimental results obtained by the digital image correlation and strain gauges so that the entire stress-strain-fields through thickness is analyzed and validated. Strain results obtained via digital image correlation, strain gauges and finite element analysis are in good agreement and the strain gauges analysis are complementary to digital image correlation in order to obtain the full-field strains in the sandwich composites.

**Keywords:** Composite sandwich beams; Strain fields; FEM; VIC3D, Strain-gauges.

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## 1. Introduction

Different face and core materials can be used in sandwich structures depending the practical employment. Steel and aluminum are ones of the most widely used metallic materials for the faces due to its high mechanical strength and low cost, while among the non-metallic materials, the laminated composites are the most used ones due to their high elasticity module and higher weight-bending stiffness, such as basalt fibers reinforced polymer (BFRP). The basalt fibers exhibit excellent properties such as high strength, high elasticity module and corrosion resistance. For the core, one of the most commonly used materials are in the form of foams, being the most used polyurethane and polystyrene. [1, 2]

Sandwich structures with its high stiffness and strength-to-weight ratio are quickly becoming the main structural components in many state of the art constructions. It is mainly used as bending components and are formed by materials with very different resistance in the faces and in the core. Therefore, the behavior of such structures under bending conditions must be studied. In this work, sandwich composites structures made of two different face materials (aluminum and BFRP) under tree point pending (3PB) and four point bending (4PB) experimental tests were analyzed using strain gauges and digital image correlation (DIC) to evaluate and characterize the stress-strain-fields. Historically, standard practices for assessment of material stress-strain constitutive relations have been based on resistance strain gauge measurements [3]. However, the strain gauge measures the average strain over the gauge area, excluding the interlaminar properties. On the other hand, accurate non-contact full-field deformation measurement techniques, such as DIC allows the assessment of entire specimen surface [4, 5]. Furthermore, finite element analysis (FEA) using Siemens NX 3D finite element models were carried out to access the experimental results.

## 2. Experimental

### 2.1. Material

Aluminum and BFRP composite were used on the sandwich structures as face materials. For the core, polyurethane plates were used with two different thicknesses: 20 mm and 30 mm, enabling a wider range of tests and results to be analyzed. The sandwiches with aluminum faces were prepared by cutting individually the polyurethane and the aluminum plates into rectangular sections (390 mm x 70 mm). SikaForce-7710 L100 was used as an adhesive and 5 kg of weigh during 24 hours was applied to glue the aluminum faces to the core. The BFRP sandwiches were produced by hand lay-up with four layers of twill 2/2 with lay-up [(0/90)/(45/-45)]<sub>s</sub> of basalt fiber fabric Basaltex<sup>®</sup> TM BAS 220.1270.T per side to produce

de faces of the polyurethane core. Vacuum bag were used during 24 hours with 850 mPa of pressure at ambient temperature. Thus, plates with rectangular sections (430 mm x 780 mm) were cut into 390 mm x 70 mm specimens with a diamond circular saw. The main properties of the materials used in this work are presented in Table 1 and Table 2.

**Table 1.** Aluminum and Polyurethane Properties.

	$\rho$ [kg/m <sup>3</sup> ]	$E$	$\nu$	$G$	Thickness [mm]
aluminum	2780	73 GPa	0.33	-	t=1
polyurethane	40	9.2 MPa	0.33	3.46 MPa	c=20
					c=30

**Table 2.** BFRP Material Properties.

	$\rho$ [kg/m <sup>3</sup> ]	$E_{11} = E_{22}$ [GPa]	$E_{33}$ [GPa]	$\nu_{12} = \nu_{13}$	$\nu_{23}$	$G_{12} = G_{13} = G_{23}$ [GPa]	Thickness [mm]
BFRP composite	1538	16	3.2	0.33	0.35	2.7	t=1

## 2.2. Testing

3PB and 4PB tests according to ASTM393-00 [6] were applied to the previously prepared sandwiches to measure the flexural properties. All specimens were tested and the load vs displacement plot were recorded using an Instron 5566 universal test machine equipped with a 10 kN load cell with a crosshead displacement rate of 2 mm/min.

Both situations: short- and long-beam conditions were tested. In the 4PB test the short- and long-beam were induced with the application of a quarter and a third span length respectively. This way, 90 mm and 250 mm span lengths were used in the 20 mm core thickness specimens and 136 mm and 340 mm spans lengths were adopted in the 30 mm core thickness for mutually 3PB and 4PB test.

## 2.3. Experimental Analysis

Digital image correlation (DIC) software using VIC2D system, has been used in this work to obtain the strain fields inner the specimen. Strain gauges were also glued to the surfaces of the 3PB (bottom) and 4PB (top and bottom) specimens to obtain the strains in the surfaces of the samples.

Prior to DIC, the surfaces of the specimens were coated with thin layer of white acrylic paint. Using an airbrush, carbon black paint is sprayed over the white surfaces, creating random black and white artificial speckle pattern. The VIC2D optical system consists of a CCD camera that captures images of an experimental test and by software that makes the correlation. The longitudinal section of the specimen between the supports was defined as an area of interest (AOI) and the values of 21 and 5 were assigned for the subset and for the step, respectively (defining the mesh to be analysed) [7]. In the end of the analysis, the program provides information about the displacements and strains in each direction, through a colour gradient representing ranges of displacement or other selected variables. Sequences of images are collected as the displacement control progresses from 1, 2 and 3 mm. The images collected during the experiments are then processed using VIC2D to estimate the strain fields.

Strain gauges were also applied in the faces of the sandwich specimens to complement the VIC2D analysis.

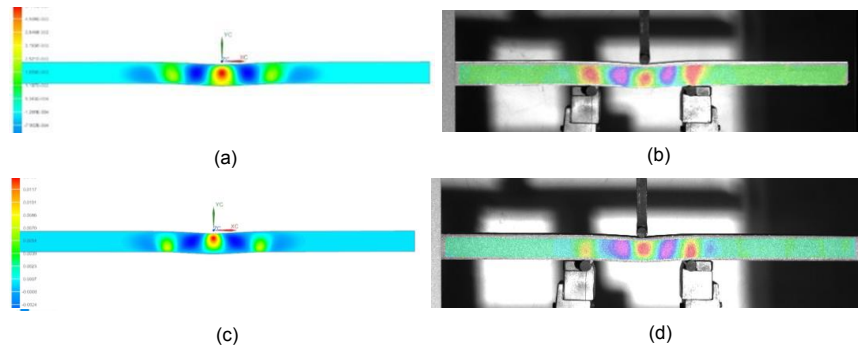
## 2.4. Finite Element Analysis

A 3D solid FEA was developed using a commercial finite element code according to Siemens NX10. Half cylinders were modeled to simulate the supports and rollers of crosshead testing machine. 8-node hexahedral solid-body elements CHEXA(8) were used. The polyurethane core and the faces (aluminum and BFRP) were modeled with 5 mm of element size in the width. It was adopted for the thickness and length directions an element size of 1 mm and 0.625 mm for the faces and for the core respectively. The half cylinders were modeled with a 0.5 mm element in all directions. The loads and constrains were applied to the half cylinders and the bonded connection between the faces and core was modeled with the surface-to-surface gluing command, while the contact between the half cylinders and the faces was modeled by the command surface-to-surface contact [8].

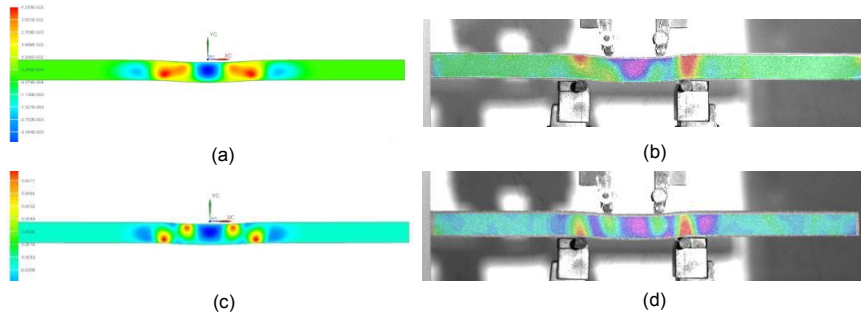
### 3. Results and discussion

An example of strain plot results obtained by FEA and VIC2D for 3PB on aluminum and BFRP short-beam specimens are present in Figure 1. Figure 2 presents the equivalent previously conditions although for 4PB tests. In overall qualitatively, FEA and VIC2D present similar strain plots.

Juntikka et al. [9] showed that sandwiches structures are in general sensitive to localized loads. An applied compressive load will cause the exposed face sheet to deform locally and, as the load increases, indentation will eventually occur induced by core compression failure, so the pressure distribution under applied load depends on the bending stiffness of the face sheet. When the face stiffness is low, the contact load is virtually transmitted straight through the face sheet to the underlying core, while for rigid skins the load is spread out, affecting a larger area of the underlying core. This behavior is shown on BFRP face specimens less stiffness presenting a more localized deformation in the location of the loading/support (areas in red) than the specimens with aluminum faces for both 3PB and 4PB tests (Figure 1(c) and (d) and Figure 2(c) and (d)).



**Figure 1:**  $\epsilon_{xx}$  contour obtained under 3PB on: (a) FEA aluminium; (b) VIC2D aluminium; (c) FEA BFRP; (d) VIC2D BFRP.



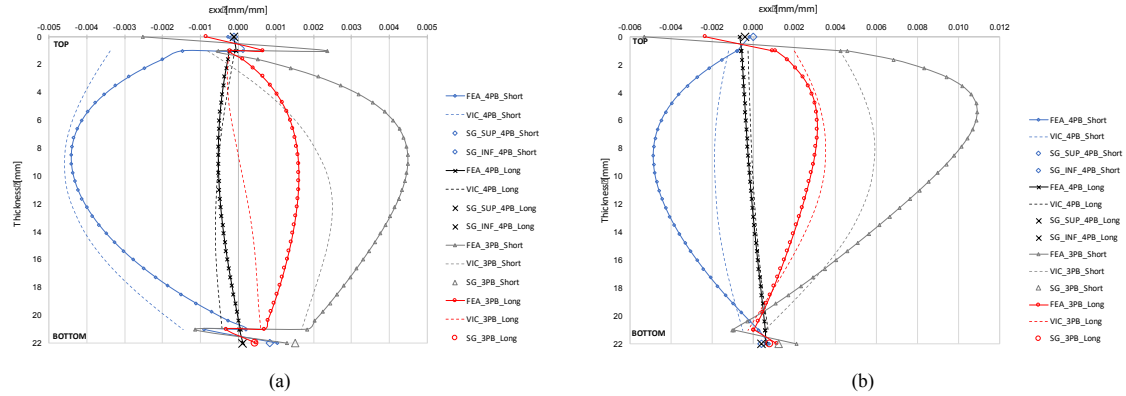
**Figure 2:**  $\epsilon_{xx}$  contour obtained under 4PB on: (a) FEA aluminium; (b) VIC2D aluminium; (c) FEA BFRP; (d) VIC2D BFRP.

Figure 3 (a) and (b) shows the  $\epsilon_{xx}$  distribution along the thickness at the mid-span length on 3PB and 4PB tests for short and long-beams on aluminum and BFRP specimens respectively. Both plots show the  $\epsilon_{xx}$  distribution obtained with the finite element (FEA) and VIC2D analysis. Additionally, average values of strain gauges' results obtained on the aluminum and BFRP face specimens are plotted. On the 3PB specimens' the strain gauge was placed on the underside at mid-span length, similarly on the 4PB specimens' the strain gauges were placed on both face sides also at mid-span length.

It is clear that for both face materials (aluminum and BFRP) the 3PB tests presents a mostly positive  $\epsilon_{xx}$  distribution along thickness while the 4PB exhibits negative strains, due to shear effects suggesting compression zones. Likewise, 4PB BFRP specimens exhibit an almost linear distribution, with negative strains in the top and positive strains in the bottom, showing that it is no longer influenced by the loading/support pressure zones. Therefore, it is evident that specimens with BFRP faces presents a more localized deformation nearby the applied load region than the specimens of aluminum faces, confirmed by the higher strains observed near the top face.

The strain gauge results show that they are a complementary analysis to the VIC2D as this method cannot evaluate the face region of the sandwich composites. Strain gauges' results shows that are in conformity with the FEA.

The use of materials with different mechanical properties on the faces and core, causes a discontinuity in the deformed planes face-to-face at the interface. This effect is known as "zig-zag" and can be observed especially on specimens with aluminum faces (Figure 3a). Also, the FEA results of the aluminum face specimens shows a large discontinuity in the  $\epsilon_{xx}$  distribution in the core-face interface revealing an adhesive failure.



**Figure 3:** Comparison of FEA, VIC 2D and Strain Gauges (SG)  $\epsilon_{xx}$  distribution along thickness at mid span length on Short and Long Beams of: (a) Aluminium; (b) BFRP.

#### 4. Conclusions

3PB and 4PB tests of sandwich panels have been performed to predict the behavior of short and long beams. The study involved experimental investigation using digital image correlation (DIC) and finite element simulation to obtain the strain-fields of face-interface-core materials under bending tests. The  $\epsilon_{xx}$  contours obtained from FEA and VIC2D have been compared and showed good agreement.

The strain results demonstrated that the BFRP sandwiches are more locally deformable by the constraints than the aluminum specimens. Short beams under 4PB present compression strains at mid-span length due to the shear effects for both specimens (aluminum and BFRP). The results of the strain gauges showed that they are a complementary analysis to the VIC2D as this method cannot evaluate the face region of the sandwich composites. Strain gauges' results show that are in conformity with the FEA. The "zig-zag" effect, due to the use of different materials on the face and core, is very evident on the specimens with aluminum faces, especially on 3PB tests with short beams.

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